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PERFORMANCE OF THE 10-kV, 5-MA PULSED-POWER SYSTEM FOR THE FRX-C COMPRESSION EXPERIMENT*

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Abstract

Performance data are presented for the 10-kV, 5-MA, 1.5-MJ pulsed-power system developed for the Los Alamos magnetic fusion facility *FRX-C*. This system energizes a low-inductance magnet for the high-power, compression heating of compact toroid plasmas. An ignitron-switched, 20-mF, 10-kV, 4-MA capacitor bank is discharged to produce the main compression field, while an inductively-isolated, 10-mF, 10-kV, 1-MA bank generates an initial magnetic field to accept the translated plasma. To date, the complete system has successfully operated for two years and approximately 2000 high-power discharges. Component performance during typical and fault-mode operation is reviewed.

Introduction

The Los Alamos *FRX-C*[1] device is a magnetic fusion experiment on which research is performed on field-reversed configuration (FRC) compact toroid plasmas. As illustrated in Figure 1, FRCs created in a field-reversed theta-pinch are translated into an adjacent coil where they are compressed by an increase in the external magnetic field from 0.4 to 2 T in 52 μs. The principal scientific objective of this experiment has been the study of energy, particle, and magnetic flux transport of FRCs in a higher-pressure regime with plasma densities and temperatures of up to $n \approx 3 \times 10^{21}$ m^{-3} and $T_i \approx 1.5$ keV.[1] The compressed plasma has a major radius of 0.06 m, a length of 0.4 m, and a thermal energy of up to 25 kJ. In this paper, we present performance characteristics after two years' operation of the compressor pulsed-power system.

Pulsed-Power System

A photograph of the experiment is shown in Figure 2. The compression magnet consists of a single-turn coil, 3.1-m long, 0.60-m o.d., 0.46-m nominal i.d., machined from type 6061/T6 aluminum plate. The vacuum inductance of the coil is 63 nH, while a 2-T vacuum B field corresponds to a magnetic energy of 0.8 MJ. The vacuum flux swing of 0.27 Wb during the 52-μs compression requires an initial loop voltage of 8.2 kV.

The magnetic energy and loop voltage are supplied by ignitron-switched capacitor banks connected to the coil through a single feed. The lumped circuit diagram for the *FRX-C* compressor is shown in Figure 3. Two 10-kV banks are discharged in parallel. First, the 0.5-MJ guide-field bank is switched to provide a pulsed output current of up to 1 MA with risetime 110 μs. This bank is crowbarred immediately after the peak current is reached. During the crowbar phase, the 1-MJ compression capacitor bank is discharged and an additional current of up to 4 MA is delivered to the load with a risetime of 52 μs. The compression bank is also crowbarred just after the maximum current is reached. A high-power isolation inductor is placed in series with the guide-field bank to reduce the compression bank current in the guide-field crowbar loop.

The capacitor banks are constructed from simple, versatile, inexpensive modules developed at LANL. The module design has been described in detail at the last IEEE Conference.[2] The compression bank consists of forty 25-kJ modules, each consisting of a single 10-kV, 500-μF capacitor (General Electric Co., Catalogue *# 30F1695*), size-D ignitrons (Richardson-National Electronics Corp., Catalogue *# NL-488A*) for start and crowbar switching, parallel-plate busbars, and a modular trigger unit. The guide-field bank consists of ten 50-kJ modules, each consisting of two 500-μF capacitors.[2] The fragile glass-metal seal around the ignitron anode bar is isolated from mechanical shock through a pair of high-current flexible braided connectors (Model *# CF 771-7.25-D6667* and *# CF 771-11-D6667*, available from the Dossert Corp., Waterbury Connecticut). The ignitron cathodes are water cooled, while the anodes are left exposed to ambient room-temperature air. An important module component is a 7-mΩ damping resistor installed in series with each start ignitron. During a standard discharge, the resistor reduces the capacitor voltage reversal and damps the ringing start ignitron current during the crowbar phase.

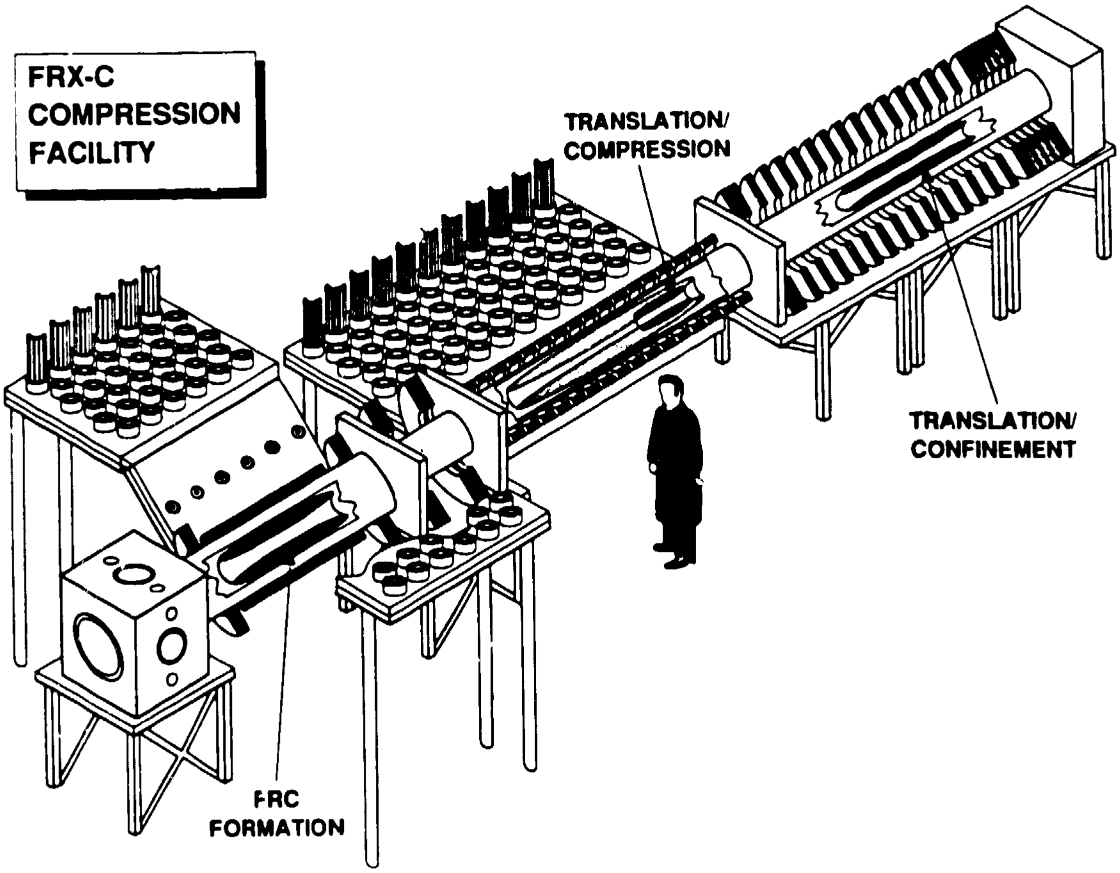

Fig. 1. Artist's conception of the FRX-C compression facility.

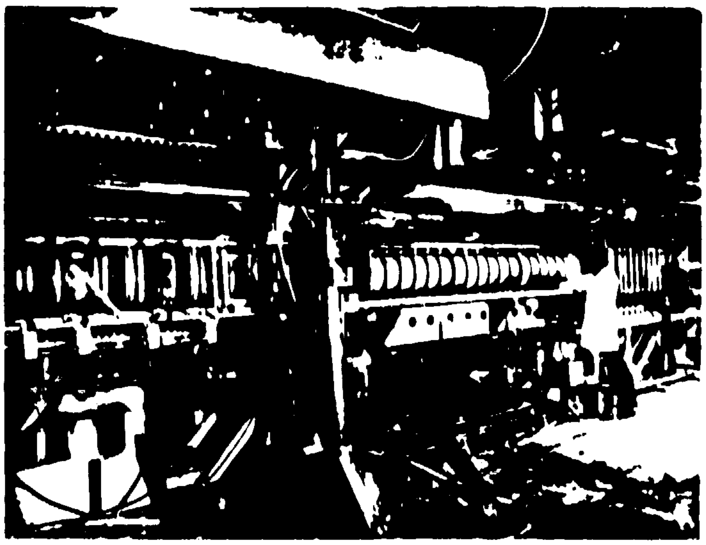

Fig. 2. Photograph of the FRX-C compression experiment

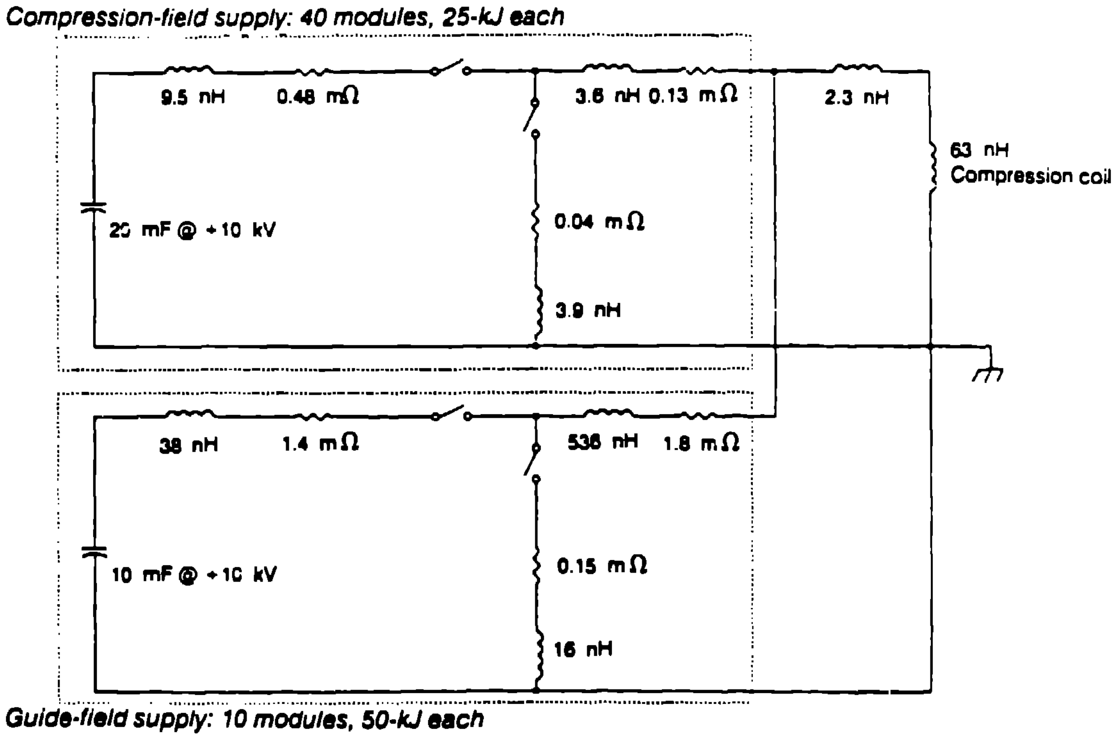

Fig. 3. Circuit diagram of the FRX-C compressor.

The pulsed-power system is operated through the FRX-C computer control system.[3] Current-controlled 12-kV, 60-kW dc power supplies (from P. Dahl Co., El Paso, TX) are used to charge the capacitor banks. Each ignitron is triggered by an isolated 4-kV, 500-A, 4-μs pulse, provided by a modular capacitor unit.[2] Trigger synchronization is guaranteed by the use of single master switches (size-A ignitrons) to conduct all of the parallel trigger ignitor currents. On every discharge, the current waveform from each module is monitored with an inexpensive, fiber-optically coupled resistive shunt,[4] digitized, and stored in the FRX-C computerized database.

A 536-nH series inductance isolates the guide-field bank from the compression bank. Most of this isolation is provided by a 462-nH, high-power inductor, consisting of a type-6061/T6 aluminum coax shorted at one end. Dimensions of the inductor are: length = 1.00 m, outer conductor i.d. = 0.91 m, center conductor o.d. = 0.10 m. Relatively thick material and welds are used in the construction so that the inductor will withstand the large pulsed magnetic forces (up to 215 tons). Approximately half of the initial guide-field capacitor bank energy is stored in the inductor during the 1-ms, 1-MA pulse.

The capacitor bank modules, isolation inductor, and load are connected by a parallel array of 720 high-voltage coaxial cables. The low-inductance cable, Belden type *YK-198*, is used on the compression bank. The higher-inductance *RG-217/U* cable is used on the guide field bank to better isolate modules from one another. The pulsed power is fed to the coil through low-inductance parallel-plate transmission lines or collector plates. The collector plates are designed to withstand large repulsive magnetic forces. For the *FRX-C* compressor, the force associated with a 5-MA discharge is 875 tons. Mechanically-strong, mylar-insulated collector plates developed for the Los Alamos *Scyllac* program satisfy these design constraints and have been recycled for use on *FRX-C*.

Performance

The FRX-C Compressor pulsed-power system has operated on approximately 2000 discharges over the past two years. A typical vacuum magnetic field waveform measured on this experiment is shown in Fig. 4.

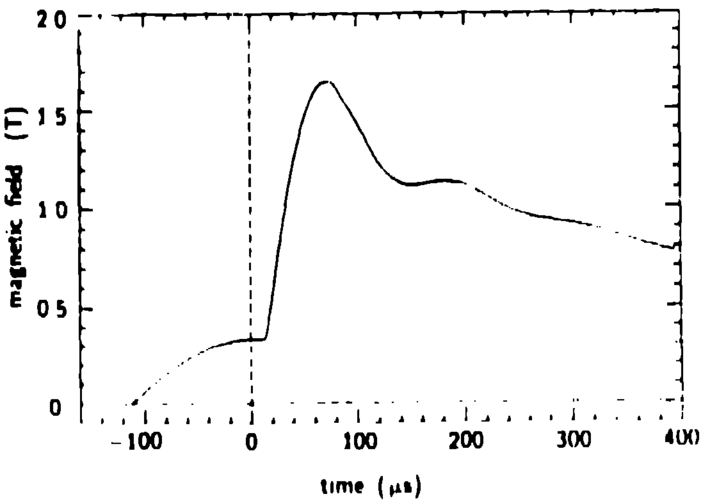

Fig. 4. Vacuum B-field waveform measured on FRX-C.

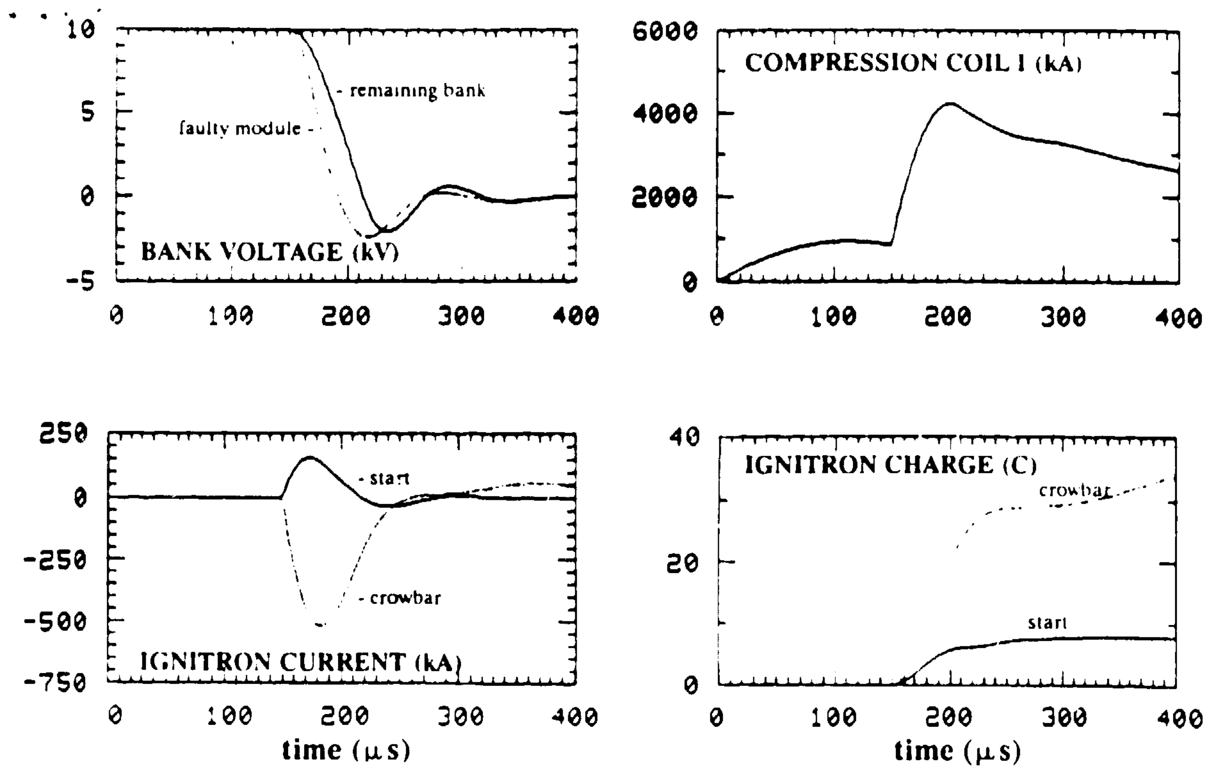

Fig. 5. Circuit simulation of a compressor module crowbar prefire.

Major system components performed satisfactorily during operations. None of the sixty high-energy-density capacitors failed. All twenty ignitrons in the guide-field capacitor bank also remained functional throughout the data run, as did all forty start ignitrons in the compressor bank. Four of the forty crowbar ignitrons in the compressor bank, however, were lost due to prefires. After the prefire, a faulty tube no longer held off the applied high voltage, and could not be adequately reconditioned. All of these failures occurred during a single two-day period when there existed an inadequate anode-cathode temperature differential on the tubes. As illustrated by the circuit simulation in Fig. 5, the crowbar prefire resulted in a reverse current of about 0.5 MA through the faulty ignitron.

During the course of these experiments, all of the ignitron trigger ignitors deteriorated, as anticipated.[2] The average ignitor-cathode resistances dropped from 315 ± 100 mΩ to 100 ± 35 mΩ (start), and 180 ± 90 mΩ to 73 ± 37 mΩ (crowbar). The alternate (unused) ignitor pin deteriorated faster, from 280 ± 90 mΩ to 55 ± 30 mΩ (start), and 185 ± 105 mΩ to 48 ± 37 mΩ (crowbar).

The two weakest components in the pulsed-power system were: (1) the flexible braided connectors attached to the crowbar ignitrons; and (2) the current-limiting resistors connected to the start ignitrons. Fifteen braided connector assemblies failed during crowbar ignitron prefires. During a fault, the braided connector wires separated from the swaged copper tabs. This failure mode proved somewhat advantageous since the braided connector acted as a relatively-inexpensive fuse which protected the ignitron. This configuration, therefore, should be considered as a cost-effective alternative to the use of ignitrons with "pig tail" anode connections in which the entire tube is usually lost during a similar fault.[5] Over the course of operations, eight resistor assemblies failed. In each case, the welded joint between the inconel strip and the nickel tab ruptured. Unlike the braided connectors, these faults occurred randomly and were not obviously linked with a fault mode.

In conclusion, the FRX-C Compressor pulsed-power system has operated for two years. The conservative design and extensive prototype testing proved useful for the observed successful and reliable performance. Major commercial components performed satisfactorily, while relatively inexpensive elements acted as effective fuses during fault modes.

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References

[1] D. J. Rej *et al.*, *Tilt Stability and Compression Heating Studies of Field-Reversed Configurations, Plasma Physics and Controlled Nuclear Fusion Research* (IAEA, Vienna, in press 1991)

[2] D. Rej and W. J. Waganaar, *Performance of the 10-kV, 100-kA Pulsed Power Modules for the FRX-C Magnetic Compression Experiment*, Proc. 7th IEEE Pulsed Power Conf., R. White and B. Bernstein eds. (IEEE, New York, 1989) pp. 667-670

[3] R. W. Kewish *et al.*, *Engineering Design of the FRX-C Experiment*, Proc. 9th Symposium for Engineering Problems of Fusion Research (IEEE, New York, 1982)

[4] Rita Gribble and G. A. Barnes, *A Multichannel, Optically-Coupled Spark Gap Monitor System*, Proc. 12th Symposium Fusion Engineering (IEEE, New York, 1987), pp. 600-602

[5] K. Whitham *et al.*, *Nova Pulse Power Design and Operational Experience*, Lawrence Livermore National Laboratory Report UCRL-95051 (1987)